

**DUAL-PROCESS GENESIS FOR VALLES MARINERIS BASINS AND TROUGHS ON MARS.** R. A. Schultz, Geomechanics-Rock Fracture Group, Department of Geological Sciences, Mackay School of Mines, University of Nevada, Reno NV 89557-0138 (<http://unr.edu/homepage/schultz>; [schultz@mines.unr.edu](mailto:schultz@mines.unr.edu)).

### Summary.

An improved sequence of formation for Valles Marineris depressions is proposed. It involves three key stages: (a) dike emplacement radial to Syria Planum during Late Noachian to Early Hesperian time; (b) subsidence of crustal rocks due to reduction of void space at depth during post-Early Hesperian time; and (c) regional normal faulting that overprints the ancestral basins and forms the structural troughs during Amazonian time.

### Introduction and Background.

The origin of Valles Marineris troughs and basins has remained a problem since their discovery nearly a quarter century ago [1]. Two main schools of thought appear to have emerged over the course of many investigations by independent research groups: collapse [2,3] and tectonic [4-9]. In the Collapse School, attention is usually focused on the closed depressions such as Hebes Chasma and their spectacular layered deposits. Here, there exists no obvious route for lateral removal of material that once filled the trough depression, requiring that the void be created by removal of crustal material downward in some preexisting cavity. The role of structure in forming these depressions is considered to be either minor or a by-product of trough formation by collapse. In the Tectonic School, the role of normal faulting is predominant and the troughs most consistent with this mechanism are the narrow rectangular troughs such as Coprates Chasma. The tectonic hypothesis has difficulties in accounting for the irregular outlines, and apparently constant depth, of the closed depressions such as Hebes.

In this abstract I suggest that two separate, sequential, and essentially independent, processes have collectively formed the final Valles Marineris trough system that we see today. The first stage produced the ancestral basins by downward displacement of crustal rocks, while some time later the second superimposed a set of tectonic grabens onto the filled basins.

### Ancestral Basins.

Ancestral basins (moats) have irregular shapes, 3–5 km of apparent subsidence [10], and either chaotic terrain [11] or smooth floor underlying thick sequences of the older interior deposits. Lucchitta and Bertolini [12] suggested that these large parts of the Valles Marineris trough system subsided earlier than the more rectangular troughs such as Coprates Chasma. This interesting hypothesis, supported by later detailed work [10,13], is based in part on the presence of large, high-standing remnants of older interior deposits in southern, irregularly shaped troughs (such as Melas Chasma) and in the southern parts of rectangular troughs such as Candor Chasma. Because the northern parts of several troughs stand at lower elevations than the adjacent older interior deposits, and given a lack of evidence for erosional transport of the older interior deposits along the trough floors [10], it appears that the northern trough floors

represent a later stage of fault-controlled subsidence that defines a single large, composite graben in the northern parts of Ius, Melas, and Coprates Chasmata [3,4,7,14].

### Problems with the Collapse Hypothesis.

In the collapse hypothesis, rock is thought to drain downward into subsurface voids. The voids have been postulated to be open tensile cracks [2], although how the cracks remain open, at tens of kilometers depth, to accept the draining rock is not obvious. Drainage of rock requires that the floors of the troughs lie at or near the angle of repose ( $30^\circ$  for common rock types), or steeper. However, topographic studies of the floors of many troughs, postulated to have formed by collapse [15], show that they are level. These two problems would appear to define insurmountable flaws for the collapse hypothesis.

### A Subsidence Mechanism for Ancestral Basin Formation.

The morphology and geologic relationships appear to require that the floors of irregular depressions (ancestral basins and Hebes Chasma-like troughs) be lowered 3–5 km from the plateau surface. A different mechanism is proposed here. Creation of void space at depth, perhaps by magmatic heating of lenses of ground ice, causes contraction, deformation, and eventual closure of these voids. The closing voids act as either anticracks (for planar subhorizontal cavities) or deflating magma chambers [16], and for sufficient ratios of width to depth, can interact mechanically with the planetary free surface, producing a subsidence profile. The void and surface do not need to be connected for this to occur.

Subsidence of surface rocks is associated with localized flexure, and failure, near the edges of the subsided region, leading to nucleation of normal faults that eventually bound the subsiding depression. In this scenario the floors of the depressions remain relatively flat and level, matching the photoclinometric observations, and normal faulting is only a minor component in the subsidence process; its map pattern is expected to be irregular, reflecting a coupling between the geometry of the voids at depth and near-surface structure that is likely exploited as the newly formed faults propagate downward.

The voids themselves provide an example of roof design under relatively shallow conditions [17]. The span of the void is limited by void size, depth, rock mass characteristics, and *in situ* stress. The roof beam can fail by any of three mechanisms including compressive failure, shear failure, and buckling; specific conditions can be evaluated quantitatively using standard techniques from mining engineering [17]. The right set of conditions can lead to void collapse and associated subsidence of superjacent rock strata.

### Structural Control of Ancestral Basins.

The basins are crudely aligned with the later structural troughs, suggesting common structural control [1]. Spencer and Fanale [3] pointed out some of the difficulties with the notion that a Valles Marineris-scale fault set underlies the basins and provides control; in addition, scaling relations for such large faults [14] would seem to preclude faulting as the means of structural control.

Recent work by Mége and Masson [8,18] suggests that uplift of the Syria Planum volcanotectonic province [19] during late Noachian to Early Hesperian time may have led to extensive radial dike emplacement concomitant with the volcanic resurfacing. Local extrusions of flows have been observed along some of the radial grabens [19], supporting Mége and Masson's hypothesis. They further suggest that many of the collapse depressions in the Valles Marineris region (such as south of Coprates Chasma) overlie dikes. This attractive hypothesis [18] implies that later deformation in Tharsis, centered farther north, could both have exploited the preexisting structural fabric (radial dikes and grabens) and account for the slightly different orientation of pit-crater chains and adjacent faults and grabens [7]. It is possible that radial dike sets, several kilometers deep [18], provided the structural control for the ancestral basins without the need to invoke prebasin regional faulting.

Given the apparently long period of time between faulting centered on Syria Planum (Late Noachian to Early Hesperian) and formation of the ancestral basins (Late Hesperian or Middle Amazonian [1]), dikes probably were not a significant source of heating of crustal rocks. Instead, additional heat sources appear required; high heat flow related to rifting [20] and a mantle plume [18] have been suggested to be associated with the later development of Valles Marineris.

### Conclusions.

A combination of initial subsidence of irregularly shaped depressions, forming the ancestral basins, followed by deposition of thick sequences of the older interior deposits, formed the first stage of trough formation. This stage may be related to the formation of high topography extending northeastward from Syria Planum, along with dike emplacement. The second, later stage involves superposition of regional-scale normal faults, associated with loading stresses from Tharsis, onto the same general area occupied by the previously formed subsidence depressions. Either the subsurface voids or the subsidence depressions may have served as initial perturbations to the regional extensional stress field, permitting localization of the central Ius-Melas-Coprates Chasma rift graben in its present location. Although both these separate processes have produced the final trough system, it appears neither sufficient nor necessary to invoke only one mechanism, and exclude the other, to produce the Valles Marineris.

**References:** [1] Lucchitta et al. (1992) in *Mars*, 453–492. [2] Tanaka and Golombek (1989) *Proc. LPS 19th*, 383–396. [3] Spencer and Fanale (1990) *JGR*, 95, 14,301–14,313. [4] Blasius et al. (1977) *JGR*, 82, 4067–4091. [5] Frey (1979) *Icarus*, 37, 142–155. [6] Masson (1985) *Adv. Space Res.*, 5(8), 83–92. [7] Schultz (1991) *JGR*, 96, 22,777–22,792. [8] Mége and Masson (1996) *Planet. Space Sci.*, 44, 749–782. [9] Schultz (1995) *Planet. Space Sci.*, 43, 1561–1566. [10] Lucchitta et al. (1994) *JGR*, 99, 3783–3798. [11] Komatsu et al. (1993) *JGR*, 98, 11,105–11,121. [12] Lucchitta and Bertolini (1990) *LPS XX*, 590–591. [13] Peulvast and Masson (1993) *Earth Moon Planets*, 61, 219–248. [14] Schultz, (1997) *JGR*, 102, in press. [15] Golombek et al. (1996) *JGR*, 101, 26,119–26,130. [16] Zuber and Mouginis-Mark (1992) *JGR*, 97, 18,295–18,307. [17] Brady and Brown (1992) *Rock Mechanics for Underground Mining*, Chapman & Hall. [18] Mége and Masson (1996) *Planet. Space Sci.*, 44, 1499–1546. [19] Tanaka and Davis (1988) *JGR*, 93, 14,893–14,917. [20] Anderson and Grimm (1995) *LPS XXVI*, 39–40.